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Final Report

Development Of A Material Property Database On Selected Ceramic Matrix Composite Materials

Submitted by:

Dr. Kamala Mahanta
Department of Physics and Astronomy
State University of New York College
Oneonta, New York 13820

To:

Mr. Ray Miller, GP16
Procurement Office
NASA/George C. Marshall Space Flight Center
MSFC, Alabama 35812

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INTRODUCTION

Ceramic Matrix Composites possess the attractive properties of ceramics such as high melting temperature, high strength and stiffness at high temperature, low density, excellent resistance to environmental effects combined with improved toughness and mechanical reliability. This breed of material has been considered to be an enabling technology with potential for use in systems that demand far greater material performance than what is currently available with superalloys and other candidate materials for such applications.

However, it is obvious that for any serious commitment of the material toward any of the intended critical thermo-mechanical applications to materialize, vigorous research has to be conducted for a thorough understanding of the material properties of CMCs.

This need to make the high technology of CMCs mature has led to the characterization of materials such as C/SiC, SiC/SiC, SiC/Al_2O_3, SiC/Si_3N_4, SiC/glass, SiC/C, SiC/Blackglas all over the world. A significant amount of data has been generated by the industries, national laboratories and educational institutions within the USA.

NASA/Marshall Space Flight Center have been collecting the "pedigreed" CMC data for storage into a CMC database within its materials database system MAPTIS (Materials and Processes Technical Information System).

The task of compiling the CMC database requires effort in various directions which may be represented by the following diagram:

CMC Database In MAPTIS

Data Acquisition	**Data Analysis**	**System Development**	**Data Transfer**
Phone Contact Lab Visits Data From Literature	Literature Search For Models For Data Validation	Hardware & Software Compatibility & Procurement	Screen and Input File Generation In MAPTIS
	Reading Reports to Check For Adequacy Of Information On the Material, Test Techniques and Material Properties		

This CMC database is designed to help NASA/MSFC's scientists and engineers in their in-house design and development projects and will be available to all national and international MAPTIS users in support of the global effort toward the progress of CMC application.

Progress of Work:

The work on system development and data transfer is complete; the data acquisition is an ongoing process and the data analysis part of the project has been handled partially due to the limited scope of the contract. Future possibilities for data analysis have been mentioned in the "pedigreed data part" of the report.

TASK I: Expansion of the list of Contacts

The task of compilation of the CMC database in NASA/MSFC's MAPTIS requires unrelenting effort toward contacting the CMC data sources with the intention of collecting as much of the latest data as possible. The database aims at being global so that it can assist interlaboratory collaboration on CMC research.

This objective is best served by establishing contact with all possible sources of CMC data. The current list contains the following:

> DuPont Lanxide, Williams International, Southern Research Institute, McDonnell Douglas, Wright Patterson AFB, Dow-Corning/Kaiser, BF Goodrich, Pratt and Whitney, NASA/Lewis, Oakridge Laboratory, Voight Corporation, Boeing, Northrop/Grumman, Cindas/Purdue, General Electric, Lockheed/Martin, University of Michigan.

It has become increasingly difficult to acquire data owing to reluctance on the part of the data sources. Boeing was tried for well over two years without any success. GE/NASA-LERC have recently (May/June, 1997) promised to send the High Speed Civil Transport(HSCT) data in a limited manner.

TASK II: Data Collection

The process of data collection is comprised of phone contact, lab visits, literature search.

Phone Contact:

While maintaining contact with the data sources who have already supplied CMC data, effort has been made to acquire data from McDonnell Douglas, Dow-Corning/Kaiser, Pratt and Whitney, Boeing, Northrup/Grumman, Cindas/Purdue, Lockheed/Martin. Additional leads need to be pursued.

Lab Visits:

These visits have been found to be very useful for the database. During the 1994 and 1995 Summer Fellowships, trips were taken to Southern Research Laboratory at Birmingham, Alabama and Oakridge National Laboratory in Tennessee. Generally, the visits have the following format:

1. Individual discussions with the CMC research personnel in the lab.
2. Tour of the Mechanical, Thermal and other properties test facilities and the lab in general.
3. Collection of reports that carry the bulk of the pedigreed data, published and unpublished data of exploratory nature generated in the lab visited and other recent publications presenting data and concepts relevant to CMCs.

An additional trip was taken in July, 1996 to NASA LERC at Cleveland, Ohio which comprised of a conference with the Turbomachinery group followed by a tour of the experimental facilities.

Samples of sources of data formatted for storage into MAPTIS:

NASA Lewis/Rocketdyne/GE/Brockmeyer and Schnittgrund[2]: Ceramic Composites for Earth-to-Orbit Engine Turbines

DuPont Lanxide/Wright Patterson AFB[3]: C/SiC Turbine Rotor for an Expendable Missile Engine

WPAFB/Williams International/DuPont/Dow-Corning-Kaiser/General Atomics[4]: Ceramic Composites such as HPZ/SiC, C/Si_3N_4, SiC/Al_2O_3 (with SiC_p) for combustor components in the WR24-7 engine.

Southern Research Institute/WPAFB[5]: Ambient and Elevated Temperature behavior of C/SiC composites

The following gives an overview of two of these reports.

1. **Ceramic Composite Turbine Component Evaluation: Williams International Report**

Contains information on flat panel and combustor component (combustor cover and primary plate) testing of four CMC's, namely, DuPont Lanxide fabricated HPZ/SiC (CVI) and Nicalon/Al_2O_3(SiC_p reinforced) via DIMOX, General Atomics fabricated C/Si_3N_4 via a forced flow thermal gradient CVI method and Dow-Corning/Kaiser fabricated Nicalon/SiNC via Polymer Infiltration and Pyrolysis (PIP). The data presented in the report are comprised of mechanical property tests conducted at the University of Michigan, thermal conductivity tests at Purdue University and thermal expansion tests at Harrop Industries and of as received as well as engine tested data. The report also carries information on the use of Non Destructive Techniques (NDE) such as Thermal Wave Imaging as well as stress analysis data.

2. **Turbine Rotor Development Program: DuPont Lanxide Composites, Inc. Report**

Presents data on a silicon carbide matrix reinforced with carbon fibers (C/SiC) generated with the objective of developing and demonstrating the technology necessary to produce a CMC turbine rotor for a missile engine. A variety of physical and mechanical data show the effect of optimum fiber structure, reinforcement unit cell size, porosity and fiber volume, oxidation protection. Information on NDE techniques as tools for the evaluation of infiltration of rotor shaped test articles (C/SiC rotor disks), identification of optimum steps between CVI cycles to machine thick CVI parts etc. have been also incorporated. Blade and disk subelements were developed for rig evaluations to address critical areas of concern for structural requirements unique to the blade root and rotor bore regions of a turbine rotor.

Literature Search:

References 1 and 6 have been identified as sources of useful data. Another interesting set of data is likely to be obtained from the ORNL reports, an example of which is the composite thermal properties presented in the CFCC supporting Technologies Bimonthly Report for August-September, 1994 submitted by ORNL to the DOE.

Some of the research data and software of interest have been discussed in Task V.

TASK III: Configuration of the hardware/software system and the process for data transfer into MAPTIS

MAPTIS in its current form being unable to read in graphs or images directly, the following has been established as the effective system/procedure for data transfer and storage.

The Digitizer:

The graphs and images have to be turned into ASCII files for input into MAPTIS. The SUMMASKETCH II PROFESSIONAL digitizer and the supporting software called "ROCKWORKS" which contains a digitizing software has been used for this purpose.

This setup converts graphs into x-y files (also xyz files if necessary) which is then edited to be in the format designed for the CMC database in MAPTIS.

The information regarding the data source, material (fiber, matrix, coating), environment, text technique, etc. as relevant to each graph is typed onto a screen specially designed for that purpose. An overview file and a Help file will be there to help the user with the use of the database.

The Scanner:

An additional hardware/software need has arisen for transfer of the tables and other non-graphical information by the data sources. It would be impractical to type the tables into a DOS text file manually. A scanner driven by an appropriate software has been anticipated to be adequate for this. A search for information on scanner and software has led to the HP SCANJET 4C CLR/GRAY scanner and the image editing software Corel PHOTOPAINT for PC as a suitable configuration for the purpose stated above.

<u>NOTE</u>: The digitizer and scanner have been used to format the data files for MAPTIS. An OCR software has been used on the scanner for transfer of tables.

Since this contract intends to provide practical experience and financial benefit to the undergraduate students at SUNY, Oneonta, several students have been employed to do the work of data preparation.

TASK IV: Search for Pedigreed Data

It is essential to search for "pedigreed" data for the database to be useful to scientists and engineers who wish to research the field of CMC application. Efforts made to achieve this have been in several directions.

a. A request sheet is sent to the suppliers of data desiring information on:

Fiber Reinforcement type (pre/post production heat treatment, tow count coating information)

Fabric Architecture (complete description)

Matrix information (material, process, additives)

Composite information (fiber volume, density, porosity)

Property information (specific geometry, test method with key parameters such as loading method and rate, heating method and rate)

Test organization: (techniques, mechanical, thermal, physical properties, shock testing, environment, NDE testing)

Proprietary restrictions on distribution of data

Leads to other sources of data.

The responses usually come in the form of reports and published papers.

b. Questions are asked about experimental techniques applied to generate the data in telephone conversations and after receiving the report.

The reports submitted by the sources of data usually carry ample information on the generation of the data. A thorough reading of the reports is vital to seeing the quality of the data. The information directly related to the data is extracted for input into MAPTIS.

c. Visits to labs have been found to be extremely valuable in getting firsthand information about the validity of the experimental techniques as well as in acquiring data.

Example: During the 1994 Summer Fellowship, Oakridge National Laboratory (ORNL) in Tennessee was visited and the visit comprised of

1. Individual discussions with the CMC research personnel at ORNL.
2. Tour of the Mechanical and Thermal properties test facilities and the labs in general.
3. Collection of ORNL reports, published and unpublished data generated using ORNL fabricated CMCs and other recent publications of data and concept related interest.

Southern Research Institute at Birmingham, Alabama was visited during the 1994 Summer Fellowship and the visit was similar in format.

The visit to NASA-LERC was also similar but no report could be acquired.

Visits are also intended to: DuPont Lanxide, Williams International, University of Michigan, Wright Patterson AFB.

In this process, it has been considered important to keep in mind the critical issues in testing CMCs, some of which are noted below.

Critical Issues in Testing CMC's[6]:

Specimen Design:

Test specimens may be: Straight sided or Dog bone, cylindrical or flat. DuPont used a blade subelement (a tensile coupon) with a gage section of elliptical shape, to simulate the leading edge of the rotor blade.

Finite Element Methods can be used in the design of specific test specimens to ensure that stresses are applied where needed. However, FEM cannot have, readily incorporated into it, the very localized changes in stresses and strains resulting from changes in fiber architecture.

Gripping Scheme, Load Train Design, Heating Methods, Furnace Materials Requirements For Testing are some other issues.

Measurement Techniques:

Temperature: Thermocouples (limit 1650°C) and Optical Pyrometers (non-contacting, no temperature limit; but do not work well at mildly elevated temperatures) - SRI use both. ASTM standards are available for calibrating temperature measuring equipment.

Strain: Strain Gauges, Laser Dimension Sensors, Clip on extensometers and Quartz Rod (or other high temperature rod) extensometers. The choice depends on specimen geometry, test geometry and conditions as well as the degree of precision required.

Strain Gauges: adequate for room temperature measurements; but not so for mildly elevated temperatures.

Laser Dimension Sensors and Clip on Extensometers: do not have the required precision.

High Temperature Rod Extensometers: are to be focused on. The specimen deformation can be transferred to the contact rods via pin holes, grooves and grooved paint, all three of which work equally satisfactorily under conditions appropriate for them. The choice depends upon the specimen (whether it is coated) and the temperature of the test (the paint can creep).

Commercially available extensometers and their thermal limits are:

Water Cooled Extensometers:	up to 500°C
Quartz Rod Extensometers:	up to 1000°C
Capacitance Extensometers:	up to 1600°C

Bending moment being a major concern, strain should be measured on more than one side of the specimen. This is made necessary by the fact that specimens are heterogeneous and may be bent or warped as a result of the manufacturing or fabrication process and cannot be corrected by machining or grinding due to other testing constraints.

At Oakridge Lab, they have acquired capacitance extensometers; however, the measurements are made only on one side of the specimen.

Control Variables: Temperature, Heating Rate, Environment, Load and Loading Rate

While preparing the data tables for MAPTIS, care has been taken to extract information on these factors and tag them onto the numerical data on the variety of tests.

TASK V: Literature Search for Research Data, Models and Software

The following publications are likely to provide valuable information toward the selection of data for the database.

1. High Temperature Behavior of Ceramic Composites; edited by S. V. Nair and K. Jakus; Butterworth-Heinneman, 1995.

2. Ceramics and Ceramic Matrix Composites: Flight Vehicle Materials, Structure and Dynamics, Vol. 3, edited by S. R. Levine, A. K. Noor, S. L. Venneri, 1992.

3. Ceramic Matrix Composites : Advanced High Temperature Structural Materials : Materials Research Society Symposium Proceedings, vol 365, edited by R. Lowden, M. K. Ferber, J. R. Hellman, K. K. Chawla, S. G. DiPietro.

The literature search has made available data on some of the less studied properties and incorporating those into the database may be beneficial to facilitating interlaboratory comparison for the discerning of the testing reproducibility and limitations, material behavior and its variability for Ceramic Composites.

CMCs have been known to have their stress strain and damage tolerance behavior significantly influenced by the strength of the fiber-matrix interface.

Examples of research data on interface behavior are shown below:

1. E. Lara-Curzio, M. K. Ferber, and R. A. Lowden: "The Effect of Fiber Coating Thickness on the Interfacial Properties of a Continuous Fiber Ceramic Matrix Composite", Ceram. Eng. Sci. Proc., 15, 5 (1994) 989-1000.

The characterization of the interfaces and their properties (co-efficient of friction, residual clamping stress, residual axial stress and debond stress) in continuous fiber reinforced ceramics is an essential part of CMC characterization.

The forces between the fibers and the matrix in a CMC can be modified by introducing interphases (such as Nicalon fibers coated with carbon and SiC using polypropelene and a mixture of methyltrichlorosilane and H_2) that protect the fiber during processing. Fiber pushout tests with variation in coating thickness yields information on changes in fiber bonding and sliding characteristics[8]. The summary of the results of the tests reported in ref 8 shows the following:

1. The interfacial shear stress for a SiC (Nicalon)/ Graphite/SiC CFCC decreases when the thickness of the fiber-matrix interphase layer increases from 0.03e-06m to 1.2e-06m.

2. The co-efficient of friction decreases with increasing coating thickness.

2. C. H. Henager, Jr., R. H. Jones: "Environmental Effects on Elevated Temperature Subcritical Crack Growth of SiC/SiC Composites", presented at the meeting on "Critical Issues in the Development of High Temperature Structural Materials", March 7-12, 1993, Kailua-Kona, Hawaii.

The environmental effect on crack growth in CMCs has been reported in terms of crack velocity versus stress intensity measured in different environments.

Although CMCs are expected to have the chemical stability and resistance to corrosion observed in most ceramics, the relatively porous matrix resulting from the CVI technique of manufacture fails to protect the fibers from the environment so that the fiber matrix interface that provides the CMC with strength and toughness becomes vulnerable and a factor of concern, especially for long-term durability of the material.

Time dependent crack growth, know as subcritical crack growth or slow crack growth (SCG), seems to affect the long-term life of the CMC structural materials with pre-existing flaws at elevated temperatures. The environment can damage the bridging reinforcements by penetrating into the reinforcement-matrix interface.

Crack velocity data as a function of stress intensity in inert and aggressive environments (2000, 5000, 10,000, and 20,000 ppm O_2) have been studied and presented.

3. R. H. Jones, C. H. Henager, Jr. and C. F. Windisch, Jr.: "High Temperature Corrosion and Crack Growth of SiC/SiC at Variable Oxygen Partial Pressures".

Continuous fiber CMCs developed for high temperature applications due to their high temperature strength and corrosion resistance have the desired fracture toughness imparted by a thin interface layer between the matrix and fiber. This interface layer (C or BN) provides load transfer to the fiber equipped with an interface fracture strength that creates a pseudodurability which can be attributed to the absorption of energy during interface fracture and fiber pullout at stresses exceeding the fiber interface fracture strength.

A 200-nm to 1,000-nm fiber/matrix interfacial layer of C or BN, used successfully in many CMCs, tends to lose mass in oxidizing environments in spite of the formation of the protective SiO_2 layer causing serious degradation of the CMC's structural properties.

The effect of oxygen partial pressures on the weight loss and time dependent sub-critical crack growth of SiC/SiC composites [8 ply Nicalon fiber cloth ($0^o/90^o$) and CVI β-SiC with C interfaces (1 μm thick) deposited on the Nicalon fibers before the β-SiC CVI step] has been studied.

Thermal Gravimetric Analysis (TGA) and Sub-Critical Crack Growth (SCG) measurements were taken. The dependence of crack velocity on applied stress intensity has been shown as V-K curves. A 2-D micro-mechanics model was developed for the prediction of crack velocities in an idealized composite under conditions of fiber creep and interface removal.

3. ORNL's Bi-Monthly Report on CFCC Support Technology subtask 2.1.3 - October/November 1993.

The growing trend of substantiating experimental data with the currently available theoretical models seems to be accompanied by an additional CFCC support technology that takes advantage of computer codes.

The UMAT routine interfaces well with ABAQUS and the CLASS code developed by the Materials Sciences Corporation (MSC) facilitates CMC modeling.

The CLASS code enables the prediction of composite material properties which may be directly input to general purpose finite element analysis codes and is therefore ideally suited for predicting the behavior of CFCCs.

CLASS is a general purpose laminate analysis program which permits maintaining a database of the properties of CFCC constituents such as particles, fibers, matrices, layers or laminate subelements. These constituents can then be combined to form CFCC composites as desired in any two dimensional reinforcement configuration. More complex 3-D reinforcements can be constructed using the N-D version.

CLASS has the capability of modeling fully general laminate reinforcement configurations permitting the variation of particles and voids with each layer in the laminate.

Once the laminate configuration is specified, the code computes the properties for the matrix material which are to be combined particle or void materials. The resulting material properties are stored in a temporary data file and then combined with the fibers defined for a given layer. Finally the layer properties are combined to construct the defined laminate.

CLASS contains the analytical capability to predict the full three dimensional properties for a laminate, including the through the thickness properties.

Moisture and Thermal expansion co-efficients are computed, as well as the thermal conductivities and specific heat for the laminate. Strengths are estimated using several "standard" failure criteria and by internally defining standard loading conditions. Strengths can be obtained using a fist ply failure or by allowing plies to fail in matrix dominated modes until fiber failure occurs.

CLASS allows the user to enter a stress analysis section where point stress analysis may be performed. These may include fully generalized loading including combinations of forces, moments, strains and curvatures, plus added temperature changes from a stress free state. When in the stress analysis section, the user may examine the layer stresses as well as the phase average fiber and matrix level stresses and strains resulting from the currently applied loading.

There is provision for interfacing with structural analysis codes on general structural analysis through the creation of a neutral file of output properties.

The CLASS code has been anticipated to be useful in selecting pedigreed data for the CMC database in MAPTIS.

CLASS has been used to provide recommendations to TEXTRON in their material fabrication effort. Similar analyses were going to be initiated for AMERCOM for their specific material.

Future activities:

During the tenure of the contract, it was necessary to get the mechanism of data reformatting for and input into MAPTIS established first, although the task of qualifying the data in search for pedigree was considered to be one that needed most attention. The time was just about enough for the implementation of the former of the two although finer adjustments are required still. The check for quality of data has been based upon the criteria cited in task IV. The data being experimental, the quality control followed by the vendors was carefully examined and counted upon.

However, two lines of thoughts were followed in an attempt to establish additional criteria for verification of the pedigree of the data.

1. Using a software setup such as CLASS and a Finite Element Analysis software to refabricate the material and regenerate the characteristics using a design simulation to check for consistency of the experimental data. Some of the possibilities have been reported in task V above. The CLASS II software has been procured; the finite element software is yet to be.

2. Statistical Analysis performed on the data provided by the vendors to check for reliability of the data.

   Reliability and Life Prediction of Ceramic Composite Structures at elevated Temperatures by S. F. Duffy and J. P. Gyekenyesi reported as chapter 11 in ref. 6 gives an overview of reliability of CMC systems which is more closely linked with the design reliability for components made out of CMC.

   Dempster-Shafer Theory and its applications by Toshiyuki Inagaki reported as chapter 15 in ref. 14 provides a tool for representing situations in which various kinds of ignorance exist in our knowledge of information about an object. Probability theory provides us with many powerful tools in system reliability and safety engineering; however, that approach tends to be inadequate in situations with incompleteness of knowledge or available information.

   Fuzzy Sets Theory by Krishna B. Misra and its applications by Takeshisa Onishawa and Krishna B. Misra reported as chapter 14 in ref. 14 discusses a new concept called "Fuzzy Sets Theory" which is stated to have applications in the field of system reliability analysis. Safety evaluation of the analyzed system, being based on the experts' judgement, has, inherent in it, the experts' subjectivity. The objective and exact expression of reliability is based on a numerical expression of the hardware reliability or human reliability. This amounts to the actual fuzziness getting hidden behind these numbers.

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2. T. P. Herbell and A. J. Eckel: "Composites in High Speed Turbines for Rocket Engines", NASA/Lewis Report.

3. DuPont Report, October, 1994, "C/SiC Turbine Rotor Development Program".

4. Williams International Report, April, 1995, "Ceramic Composite Turbine Engine Component Evaluation"

5. Southern Research Institute Report, August, 1990, "Physical, Mechanical, and Thermal Properties of Two RCI Graphite/Silicon Carbide 2D Composite Materials at Room and Elevated Temperatures".

6. High Temperature Mechanical Behavior of Ceramic Composites: edited by S. V. Nair and K. Jakus, Butterworth-Heinemann, 1995.

7. Understanding ORACLE: J. T. Perry and J. G. Lateer, Sybex, 1989.

8. E. Lara-Curzio, M. K. Ferber, and R. A. Lowden: "The Effect of Fiber Coating Thickness on the Interfacial Properties of a Continuous Fiber Ceramic Matrix Composite", Ceram. Eng. Sci. Proc., 15, 5 (1994) 989-1000.

9. C. H. Henager, Jr., R. H. Jones: "Environmental Effects on Elevated Temperature Subcritical Crack Growth of SiC/SiC Composites", presented at the meeting on "Critical Issues in the Development of High Temperature Structural Materials", March 7-March 12, 1993, Kailua-Kona, Hawaii.

10. R. H. Jones, C.H. Henager, Jr., C.F. Windisch, Jr.: "High Temperature Corrosion and Crack Growth of SiC/SiC at variable oxygen partial pressures", presented at the Japan-USA Seminar, Development and Environmental Characteristics of New Materials, June 7-9, 1994, Mt. Hood, Oregon.

11. ORNL Report on CFCC supporting technologies submitted to the Department of Energy - Bi-monthly progress report for October-November, 1993.

12. ORNL Report on CFCC Supporting Technologies submitted to DOE: Bimonthly progress report for August-September, 1994.

13. Ceramic Matrix Composites : Advanced High Temperature Structural Materials, Materials Research society Symposium Proceedings, vol 365, edited by R. A. Lowden, M. K. Ferber, J. R. Hellman, K. K. Chawla, S. G. DiPietro

14. New Trends in System Reliability Evaluation (Fundamental Studies in Engineering 16), edited by Krishna B. Misra, Elsevier, 1993.

APPENDIX

The Overview / Help file.

Hard Copies of some data sets.

OVERVIEW

The Ceramic Matrix Composites (CMC) database includes material characterization and results. It contains data obtained from selected manufacturing and testing organizations on the physical, mechanical, thermal and thermomechanical behavior of CMC's

This overview gives the user an overall picture of the general structure/contents of the database.

The properties tested are as follows:

Physical properties: Density, Porosity, Hardness.

Mechanical properties: Tension, Compression, PEL (Percision Elastic Limit), Shear, Fatigue, Torsion, Creep/Stress Rupture, Flexure, Fracture Toughness.

Thermal Properties: Thermal Conductivity, Specific Heat, Diffusivity, Thermal Expansion, Emittance

Additionally, the data base contains a subset of "not routinely tested" property data collected from tests presented in research papers published by industries, national laboratories and educational institutions.

MATERIALS: C/SiC, SiC/SiC, SiC/Si_3N_4, SiNC/SiC, Si/Al_2O_3, SiC/Glass, SiC/SiNC, SiC/C, SiC/Blackglas

REINFORCEMENT: Continuous Fibers, (Platelets, Whiskers, Particulates will be incorporated later).

DATA-SOURCE: DuPont Lanxide, Williams International, Wright Patterson AFB, Dow-Corning/Kaiser, BF Goodrich, Southern Research Institute, Pratt and Whittney, McDonnel Douglas, NASA/Lewis, Oakridge Lab, Voight Corporation, Boeing.

REINFORCEMENT MATERIAL such as:

SiC: Novoltex, Nicalon

SiNC: HPZ

C: T-300, P-100

INTERFACE COATING such as:

Material	Process	Manufactuer
RT42/43	CVD	Chromalloy
Si3N4	CVD	UTRC

HEAT TREATED / NON-HEAT TREATED

FIBER/FABRIC ARCHITECTURE:

Tow Count, EPI, Denier, Weave,

MATRIX:

Material: SiC, C, Si_3N_4, SiNC, Glass, Al_2O_3, Blackglas
Techniques: CVD, DIMOX, PIP

LAMINATE:

Preform:
Stacking:

ENVIRONMENT: Air, Inert Gas

PROPERTIES:

Physical Properties: Density, Porosity, Hardness, Fiber Volume

Mechanical Properties:
- Tension Test:
- Compression Test:
- Shear Test:
- Fatigue Test:
- Creep/Stress Rupture Test:
- Flexure Test:
- Torsion Test:
- PEL Test:
- Fracture Toughness Test:

Thermal Properties:
- Thermal Conductivity
- Specific Heat
- Diffusivity
- Thermal Expansion
- Emittance

NON-DESTRUCTIVE TECHNIQUES: X-ray, Ultrasonic, Acoustic, Computed Tomography
Pulsed Wave Thermal Imaging.

PROTOTYPE TESTS such as:

Turbine Rotor (JETEC II)
Turbine Engine Combustor cover and Primary plate (WR24-7 engine)
MK44F T/P (Simulation of Earth to Orbit engine)

FOR SEARCH PURPOSES THE DATA BASE HAS CODES FOR :

1. Data Sources
2. Materials
3. Tests

DATA SOURCES:

Name	Code	File extent
Du Pont Lanxide	1	.dup
Williams International	2	.wil
Southern Research Institute	3	.sri
McDonnell Douglas	4	.mcd
Wright Patterson AFB	5	.wpb
Dow-Corning/Kaiser	6	.dck
BF Goodrich	7	.bfg
Pratt & Whitney	8	.prw
NASA Lewis	9	.nlw
Oakridge Laboratory	10	.okl
Voight Corporation	11	.voc
Boeing	12	.bng
Northrop/Grumman	13	.ntg
CINDAS/Purdue	14	.cpd
General Electric	15	.gne
Lockheed/Martin	16	.lmn
University of Michigan	17	.uom

MATERIALS:

Name:	Code:	Comment:
C/SiC	cs	cs1 means C/SiC made by DuPont and cs2 means C/SiC made by William International and so on.
SiC/SiC	ss	ss16 means SiC/SiC made by Lockheed/Martin and so on.
SiC/Si_3N_4	sn	sn1, sn2, sn3 as above and so on.
SiNC/SiC	ns	ns1, ns2, ns3, ...
SiC/Al_2O_3	sa	sa1, sa2, sa3, ...
SiC/Glass	sg	sg1, sg2, sg3, ...
SiC/SiNC	snc	snc1, snc2, snc3, ...
C/Si_3N_4	cn	cn1, cn2, cn3, ...
SiC/C	sc	sc1, sc2, sc3, ...
SiC/Blackglas	sb	sb1, sb2, sb3, ...
C/CAS	cc	
SCS-6/RBSN	sr	
SCS-6/HPSN	sh	
Inconel MA 754	ma	
SiC/CAS	sca	

TESTS:

Name	Code	Data File Code
Density	dn	dn1.wil, dn2.wil means density datasets 1&2 obtained from William International
Porosity	po	
Tension	tn	
Compression	cm	
Fracture Toughness	fr	
Shear	sh	
Fatigue	fg	
Creep/Stress Rupture	cr	
Torsion	to	
Flexure	fl	
Percision Elastic Limit	pl	
Coating	ct	
Conductivity	cn	
Thermal Expansion	tn	
Diffusivity	df	
Specific Heat	sp	
Emittance	em	
NDE	nd	
Prototype	pr	
Environment	ev	
% Weight Change	wc	
% Bending	pb	
Modulus of Toughness	mt	
Matrix Cracking Stress	mcs	
Ult. Strength	uts	
Proport'nal Lim Stress	pls	
Tensile Str. vs. Temp	tst	
Load	ld	
In Life Time	lt	
Retained Young's Modulus	ym	
Residual Matrix Stress	rms	

FORMAT OF THE DATA-TABLE:

The data comes in the form of two tables.

1. The information regarding the numerical data
2. The numerical data.

THE INFORMATION TABLE CONTAINS:
Material code, Designation, Composition, Public Access, Access Explanation, Data Source, Address and phone no. of Data Source, Fiber and %volume, Fabric and Architecture, Density, Load Rate, Stress rate, Strain rate, Coating, Environment, Remarks, Test code, x-axis and y-axis

THE NUMERICAL TABLE CONTAINS THE NUMERICAL X-Y DATA AND THE MATEIAL AND TEST NO.:

THE FILES LOOK AS FOLLOWS:

Test: Tension Test: Strain (mils/in) vs. Stress (ksi)
Data Source: Workshop on Thermal Mechanical Test Methods and Behavior of CFCCs June 22, 1994

LeCentre Sheraton Hotel
Montreal, Quebec

Page #: ?
Contact Person: ?
Specimen: #2-TN-0-2 70
Material: Nicalon/CAS
Matrix: CAS
Matrix Enhancement: ?
Fiber: SiC
Fabric: ?
Fabric Architecture: ?
Fiber Volume: ?
Material Density: ?
Coating: ?
Environment: air
Loading Rate: ?
Strain Rate: ?
Filename: tn0100.okl
Comments:

sca14	okl0100	tn	1	0.06	0.840
sca14	okl0100	tn	2	0.09	1.484
sca14	okl0100	tn	3	0.18	2.670
sca14	okl0100	tn	4	0.27	3.816
sca14	okl0100	tn	5	0.35	4.718
sca14	okl0100	tn	6	0.42	5.600
sca14	okl0100	tn	7	0.55	6.883
sca14	okl0100	tn	8	0.64	7.814
sca14	okl0100	tn	9	0.73	8.561
sca14	okl0100	tn	10	0.78	8.936
sca14	okl0100	tn	11	0.99	10.311
sca14	okl0100	tn	12	1.11	11.223
sca14	okl0100	tn	13	1.28	12.286
sca14	okl0100	tn	14	1.39	13.042
sca14	okl0100	tn	15	1.50	13.831
sca14	okl0100	tn	16	1.64	14.717
sca14	okl0100	tn	17	1.71	15.193
sca14	okl0100	tn	18	1.83	15.896
sca14	okl0100	tn	19	1.97	16.498
sca14	okl0100	tn	20	2.13	17.250
sca14	okl0100	tn	21	2.32	17.997
sca14	okl0100	tn	22	2.43	18.476
sca14	okl0100	tn	23	2.59	19.106
sca14	okl0100	tn	24	2.69	19.524
sca14	okl0100	tn	25	2.87	20.122
sca14	okl0100	tn	26	3.07	20.748

sca14	okl0100	tn	27	3.23	21.102
sca14	okl0100	tn	28	3.39	21.334
sca14	okl0100	tn	29	3.53	21.484
sca14	okl0100	tn	30	3.68	21.580
sca14	okl0100	tn	31	3.82	21.670
sca14	okl0100	tn	32	3.97	21.746

REQUEST FOR INFORMATION SENT TO DATA-SOURCES:

1. FIBER REINFORCEMENT TYPE

   a. Any post production treatment e.g. heat treatment?
   b. Tow size
   c. coating information

2. FABRIC ARCHITECTURE (complete description)

3. DENSIFIER (organization)

   a. Matrix material
   b. Densification Process e.g. CVI, FFTG/CVI/Polymer Conversion
   c. Additives for matrix enhancement

4. FIBER VOLUME - BULK MATERIAL

5. PROPERTY INFORMATION

   a. Specimen geometry and coupon disign and quality control
   b. Reinforcement orientation
   c. Test Method
      (Key parameters e.g. loading rate, heating method, test temperature, heating rate etc.)
   d. Testing Organizations: Test techique and property values
      Mechanical Properties, Thermal properties (CTE, Specific Heat, thermal conductivity, emittance), Physical Properties.
      : properties at both ambient and high temperatures and as functions of temperature wherever applicable.
      Also shock testing and Environmental exposures.
   e. Availability of data and relevant information.
   f. Proprietary restrictions on distribution of data.

6. Any ND testing?

7. Leads to other sources of data.

Help File

This file will help the user in following the steps required for a query.

1. Get into MAPTIS using your username and password.

2. Select option 1i from the Main menu to get CMC.

3. Select any of the report options from the Report Options menu.

By selecting option 1 for material, entering a percent sign in the Search Criteria field and then pressing Return twice all data for that report option can be received.

4. Cntrl y will take you back to the previous menu
5. Cntrl c, pressed several times, will take you out of Maptis altogether.

Test:	Maximum Stress(MPa) Vs. Cycles to Failure
Test Technique:	Low Cycle Fatigue Testing
Filename:	fg3.wil
Data Source:	Ceramic Composite Turbine Engine Component Evaluation Williams International 2280 West Maple Road Walled Lake, Michigan 48341-0200 April 1995 Final Report for Period 12 September 1991 to 12 March 1995 Contract No. F33615-91-C-5659
Contact Person:	?
Page #:	53
Specimen:	1093°C
Material:	Dow Corning/Kaiser Aerotech SiC/SiNC
Fiber:	SiC
Fabric:	SiNC
Fabric Architecture:	?
Fiber Volume:	?
Material Density:	?
Coating:	none?
Environment:	air
Loading Rate:	?
Strain Rate:	?
Comments:	

sn6	wil3	fg	1	559.12	131.80
sn6	wil3	fg	2	580.78	130.86
sn6	wil3	fg	3	641.07	131.22
sn6	wil3	fg	4	778.79	129.41
sn6	wil3	fg	5	831.07	128.42
sn6	wil3	fg	6	988.60	127.60
sn6	wil3	fg	7	1084.19	126.27
sn6	wil3	fg	8	1451.93	123.98
sn6	wil3	fg	9	1798.90	123.43
sn6	wil3	fg	10	2424.07	120.73
sn6	wil3	fg	11	2788.99	119.87
sn6	wil3	fg	12	3332.03	117.56
sn6	wil3	fg	13	6609.38	113.54
sn6	wil3	fg	14	11211.97	110.21
sn6	wil3	fg	15	13698.02	109.15
sn6	wil3	fg	16	17477.40	107.82
sn6	wil3	fg	17	44790.20	99.91
sn6	wil3	fg	18	111128.82	94.81
sn6	wil3	fg	19	139550.37	93.30
sn6	wil3	fg	20	172370.64	91.56
sn6	wil3	fg	21	210603.61	89.62
sn6	wil3	fg	22	246431.99	88.49
sn6	wil3	fg	23	313176.23	87.32
sn6	wil3	fg	24	348008.16	86.00
sn6	wil3	fg	25	362292.06	74.19

Test:	Tension Test: Ultimate Tensile Strength vs. Density
Data Source:	Wright Laboratory/DuPont Final Report, October 1994

Wright Patterson AFB
Ohio, 45433-6503

DuPont Lanxide Composites, Inc.
1300 Marrows Road
Newark, DE 19714

Contact Person:	?
Specimen:	Coupons of varying density and fiber volume
Material:	DuPont Lanxide C/SiC
Fiber:	T-300 Carbon, 1K Tow Size
Fabric:	Balanced Plain-Weave, 19 epi, Heat-treated to 3270°F (1800°C)
Fabric Architecture:	0/90 2D Layup
Fiber Volume:	38%
Material Density:	Avg. 2.1
Coating:	None?
Environment:	Air?
Loading Rate:	?
Strain Rate:	?

filename: Tn9.dup

cs1	dup9	tn	1	2.07	50.05
cs1	dup9	tn	2	2.09	52.55
cs1	dup9	tn	3	2.09	51.04
cs1	dup9	tn	4	2.10	52.28
cs1	dup9	tn	5	2.11	52.03
cs1	dup9	tn	6	2.10	56.54
cs1	dup9	tn	7	2.16	49.47

Test:	Tensile Stress(KSI)-Strain(IN/IN) curves
Test Technique:	?
Filename:	tn2.sri
Data Source:	Physical, Mechanical, And Thermal Properties Of Two RCI Graphite/Silicon Carbide 2D Composite Materials At Room And Elevated Temperatures. Air Force Materials Laboratory Wright Research Development Center Wright-Patterson AFB, Ohio 45433. August 1990 Prime Contract Number: F33615-86-C-5005
Contact Person:	?
Page #:	72
Specimen:	3-TN-WARP-2
Material:	RCI T-300 2DCC
Fiber:	C
Fabric:	SiC
Fabric Architecture:	Warp Direction
Fiber Volume:	Fraction=0.3
Material Density:	1.975 g/cc
Coating:	none?
Environment:	air? Temp=70°F
Loading Rate:	?
Strain Rate:	?
Comments:	

cs1	sri2	tn	1	0.0000	0.10
cs1	sri2	tn	2	0.0000	0.82
cs1	sri2	tn	3	0.0001	2.25
cs1	sri2	tn	4	0.0002	3.63
cs1	sri2	tn	5	0.0004	5.56
cs1	sri2	tn	6	0.0005	7.61
cs1	sri2	tn	7	0.0007	9.86
cs1	sri2	tn	8	0.0008	12.73
cs1	sri2	tn	9	0.0010	14.82
cs1	sri2	tn	10	0.0012	17.25
cs1	sri2	tn	11	0.0014	19.06
cs1	sri2	tn	12	0.0016	20.97
cs1	sri2	tn	13	0.0018	22.40
cs1	sri2	tn	14	0.0020	24.12
cs1	sri2	tn	15	0.0023	25.90
cs1	sri2	tn	16	0.0026	27.58
cs1	sri2	tn	17	0.0029	28.61
cs1	sri2	tn	18	0.0030	29.16
cs1	sri2	tn	19	0.0031	29.57